Development of a data model and a prototype information sharing platform for DEMAT machine tools

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Development of data models and a prototype information sharing platform for dematerialised machine tools

The design of typical CNC machine tools has remained relatively static over the last thirty years and gradual improvements can be classified as being evolutionary. The emerging concept of a dematerialised CNC machine tool extenuates from the need to reduce machine tool raw material use in terms of mass by up to 60%. An important requirement for this concept is a detailed catalogue of machine tool parts that links individual components, their attributes and functionalities to ensure that all mass in a machine tool adds value. This paper describes DEMAT machine tools and presents research pertaining to the development of a data model and a novel information-sharing platform that supports and enables the design of a dematerialised machine tool. It provides a unique approach to design and life cycle monitoring of machines. An experimental software system has been developed using UML machine tool data models implemented as Java classes and an SQL database is used to store machine tool component data. The database has been populated with typical machine tool components to demonstrate the functionality of the prototype information-sharing platform, when developing DEMAT machine tools.

Keywords

CNC machines, Dematerialisation, Digital Manufacturing

1 Introduction

The CNC machine tool has evolved over the past decades, however in terms of heavy rigid structure and serial axis configurations, the design has remained virtually static. (Copani et al. 2012), (Mehrabi et al. 2000) and (Wieandt 1994). The developments that have taken place can often be classified as evolutionary rather than revolutionary. With the need to reduce environmental impacts new methods are required. Machine tools traditionally consist of a cast bed for isolation of vibrations and to provide stiffness during machining. However, with the increasing use of control and software coupled with state of the art drive mechanisms, an opportunity is emerging to design new, modular, reconfigurable machine tools with significantly reduced mass. Current CNC machine tools are designed based on predefined specifications with little design flexibility. This can be problematic, as the machine tool cannot be reconfigured for different applications. The development of machine tools with modular structures is enabling a new machine tool vision, allowing the user to adapt machines to their production and product based requirements, facilitating a move towards customised manufacture. However, with customisation, component information increases. Identifying this information is key to developing logical data models that can be used to design, build and maintain customised machine tools.

This paper describes the concept of DEMAT machine tools and a data model for developing a user driven view of designing machine tools. The data model will establish logical relationships between machine tool components. The capturing and modelling of machine tool information is critical for enabling customer specific machine tool designs. The data model is used to develop an information-sharing platform (ISP), which is used to specify, design and monitor the machine tool, thereby changing the way manufacturers view their resources. The ISP also provides a mechanism to monitor, log and share machine status data across different stakeholders, whilst also generating a service-orientated approach for machine tool vendors to enhance their global competitiveness. The ISP architecture is presented alongside a case study validating the data model, database, and ISP functionality.

2 Literature Survey

In this section, a literature survey is documented to provide an overview of state of the art data, manufacturing information modelling and management systems. This is used as the basis for modelling of DEMAT machines and the development of the prototype ISP.

2.1 Data models

Data models provide methods for representing and classifying information. Resource representation of machine tools and auxiliary systems has been accomplished to some degree by Vichare *et al.* (2009), demonstrating the static capabilities of a machine tool. This method represents kinematic information of a given machine tool allowing for positioning of different components in relation to each other. This approach also incorporates extensions to existing STEP-NC standards for defining machine tool resources and is embodied in the ISO14649-201 (2011) standard. STEP-NC is based on the ISO 10303 standard for representation of product data in a computer interpretable format allowing for the exchange of manufacturing data between different systems as defined in ISO 14649-1 (2002). STEP-NC provides a method to describe a product model throughout its lifecycle (Giachetti 1999) and has been a major instigator in developing machine tool data models for representing information from a resource and kinematic viewpoint. These data models have shown the embedded capabilities of defining machine tool resources and the kinematic connections between different components. This is particularly important for developing controllers that are aware of the machines kinematic configurations. Adding greater data granularity will facilitate generation of intelligent machine tools that are aware of their capabilities. Other notable manufacturing based data model examples include work by Bugtai and Young (1998) who developed information models for integrated fixture decision-making. In addition, Hedman *et al.* (2013) used object oriented (OO) modelling of manufacturing resources with work study inputs as a method to enhance resource utilisation. A UML approach is used to express factory subsystems and workstations.

2.2 Modelling of manufacturing information and knowledge

A typical manufacturing enterprise contains information and knowledge pertaining to products, processes, design etc. Knowledge-based-systems (KBS) have been heavily researched, and are considered critical in reducing data redundancies and streamlining information flow from flexible to personalised manufacturing. Research has been conducted related to modelling of manufacturing resources and systems with the aims of improving manufacturing through increased information flow and digital models. Zhang *et al.* (1999) developed an OO manufacturing resource modelling approach for enabling adaptive process planning for increased machining process capability. Yang and Xu (2008) present a method for modelling machine tool data in support of STEP-NC based manufacturing. Liu *et al.* (2003) present research on manufacturing resource modelling based on the OO method. Zhang *et al.* (2013) propose a process comprehension method to capture and reuse manufacturing process knowledge from shop floor part programmes. Product and process information is captured in a standardised STEP-NC format and reused in a CAD/CAM system to generate part programmes for a different CNC machine. Modelling of manufacturing resources is complex as there are different data types.

2.3 Product information management

Efficient management of product information is critical to the enhancement of corporate competitiveness as described by Kim *et al.* (2001). Product data management (PDM) systems have emerged as a means with which to manage large quantities of product information. Such systems integrate and manage all applications, information, and processes that define a product, from design through to manufacture, and end-user support as discussed by Liu and Xu (2001). PDM systems focus primarily on engineering tasks and do not offer a complete data view over the entire product life cycle. As a result a new generation of software systems, Product Lifecycle Management (PLM) systems have evolved from the original PDM systems (Cheung and Schaefer 2009). Portella (2000) describe PLM systems as 'an infrastructure to support management of product definitions throughout their complete lifecycle from initial concept though to product obsolescence'. As a result, 'PLM is not considered to be a peer to enterprise application like ERP (Enterprise Resource Planning), CRM (Customer Relationship Management) and SCM (Supply Chain Management), rather, it provides a foundation on which other applications can operate in an integrated fashion as discussed by Ameri and Dutta (2005). A PLM system is the top level of the IT system and needs support from sub-systems such as ERP, SCM etc. It is only suitable for enterprises with sophisticated information management systems, which normally excludes traditional small manufacturing enterprise (SME).

The approach described in this paper is related to an enriched PDM system specifically designed for DEMAT machine tools. The ISP will represent machine tool lifecycle from negotiation and design through to monitoring and lifecycle management. Whilst the ISP will cover the lifecycle of a DEMAT machine tool, it is not considered to be a traditional PLM system requiring specific business models and support infrastructure. As a result it can be implemented by enterprises of different sizes.

3 The dematerialised machine tool vision and the information sharing platform methodology

3.1 The dematerialised machine tool vision

The term dematerialisation has been applied to a number of different scientific domains from social policy (Hezri and Dovers 2006) and economics (Coyle 1997) to engineering and sustainability (Persson 1999). It is a term that is now being used in engineering to describe and quantify the reduction in material use. Dematerialisation of machine tools is related to the removal of mass from a machine tools structure, without affecting overall capabilities and primary functions. This is achieved by using triangulated elements and active damping units with software control in place of heavy cast structures as documented by Copani *et al.* (2012) and Zulaika *et al.* (2011). Active damping control methods compensate for vibrations produced during cutting and as a consequence of machine movement. The next section of this paper presents the methodology for the design and development of the DEMAT ISP.

3.2 The DEMAT Information sharing platform methodology

The majority of CNC machine tools in use are designed not by the end user, but by the machine tool builder. The user purchases a machine that best suits their required needs. In this scenario, the user does not have control over the design of the machine tool, except for periphery equipment such as tables, spindle (in terms of max spindle speed) and controller types limiting the functionality of the machine tool. In order to develop a DEMAT machine tool specific resources have to be identified by the customer. A machine tool consists of a number of resources that function coherently to form a machine tool. These resources typically consist of components such as spindle, table and also auxiliary devises such as a retrofit 4^{th} axes. In addition these components are required to interact with each other, such as the axes in a serial machine.

The methodology for creating and using the DEMAT ISP consists of a number of phases as shown in figure 1. Stakeholders (section 3.3, table 1) must first define their machine tool requirements in terms of use and components (section 3.3, table 2). This information is then classified based on the different component family types. Once this is carried out the DEMAT data model is developed using a UML based approach providing attributes, associations and data links between different component types (section 4). The next phase is to use this information to generate the DEMAT databases (section 5.1) and finally a user interface is developed to provide the complete DEMAT ISP (section 5.2). An iterative information assessment is conducted to maximise the effectiveness of the ISP to the stakeholders and customers.

Figure 1. DEMAT ISP Methodology

The ISP consists of four phases covering the lifecycle of the machine tool: negotiation, design, monitoring and lifecycle. In the negotiation phase, the customer defines general factors such as buying price, forecasted maintenance costs, forecasted energy consumption over a number of years, potential substitution of new components by second-hand components etc. In the design phase, the user can browse and choose components to build the machine. The user can access component information: dimensions, cost, forecasted lifespan, performance in terms of accuracy, and energy consumption etc. During this process a calculation of total cost, energy consumption and maintenance can be performed to compare against targets set during negotiation.

The design of a DEMAT machine tool requires a considerable amount of information. In addition, the correct information and detail level needs to be presented to the user. For example, a spindle has a number of sub assemblies, consisting of encoders, bearings, motor housing, mounting assemblies etc. The customer does not typically require this level of information. In most cases the spindle speed, table size, working volume, controller type and maximum tool holding capabilities are the major elements of information required by the customer. Other elements, such as oils, lubricants and general maintenance issues are not typically discussed as these are assumed standard requirements for all machine tools.

3.3 Information requirements of machine tool data model

A machine tool consists of a number of connected, mechanical, electronic and electromechanical components and systems. In the most part, the user will have no access to these components and systems, in terms of design. A machine tool will have a finite set of data requirements that are common amongst all different machine tool designs. These data requirements can then be subdivided into further levels of detail, allowing the user to comprehend different component interactions. In order to gather the required information a series of end user, vendor and sub contractors were sent user requirements questionnaires to capture machine tool data requirements. Figures 2, 3 and 4 depict an example set of the user requirements information. Figure 1 provides an example of the different data requirements in terms of auxiliary devices, product, process, technology, people and machines. The purpose of this was to analyse the data requirements, the sub level categories and associations with other components.

Figure 2. An example of the different data requirements

The different data requirements are further subdivided to provide another level of detail. Figure 3 provides an example of the components associated with the machine. In this phase interactions are not illustrated. This is dealt with in the UML descriptions, which also presents attributes.

Figure 3. An example of the associated data with the machines element

Figure 4 goes in to further detail and illustrates a snap shot of some of the information pertaining to the mechanics of a machine tool.

Figure 4. An example of the different mechanical elements of a machine tool

Using this approach, the information requirements of a machine tool can be categorised based on different stakeholders, which are the machine tool builders (Ibarmia, MCM, CECIMO, CESI, NC-Service) requirements, component suppliers (Tecnalia, Micromega, D.Electron, NC-Service and Intelliact) requirements, auxiliary system (Micromega, D.Electron, NC-Service, Intelliact) requirements and end user requirements. Table 1 below illustrates the different stakeholders involved in gathering the DEMAT machine tool information requirements. Each stakeholder was asked whether they would define or use a specific component. Table 2 documents the captured information.

Table 1. DEMAT stakeholders

Table 2: The different stakeholder information requirements

4 Dematerialised machine tool data models

4.1 Representing the information of a machine tool

The development of a machine tool data model will provide and enable the generation of a user driven approach for designing and implementing DEMAT machine tools that best suit a user's requirements, using a range of specific components identified in table 2. Furthermore it will provide an increased level of machine tool customisability enhancing production capabilities. The data model identifies and classifies different machine tool components and should also show the different attributes and links between the different components.

4.2 Data model for a DEMAT machine tool

There are different methods and software tools that can be used to model representations of a machine tool, with the most common standardised method being EXPRESS-G (Arnold and Podehl 1999). The key aspect of designing and manufacturing a DEMAT machine tool relies on the capability to digitally represent components and connections of the machine tool. This information can then be used to generate machine tool specifications based on a set of user requirements. In addition, the digital representation of the components can be used to show machine tool component interactions on a kinematic and dynamic level. Moreover, the same method can also be used to capture and store component information from part suppliers.

In order to model machine tool information, UML was chosen as the modelling language as this allows for modelling of different attributes, associations and linkages. This also provides an OO method in which to envisage all separate components and provide component information in the form of attributes and associations. Moreover, it provides a method to develop machine tool component classes, which can then be used to generate examples of specific machine tools.

The machine tool builder will use machine component information, such as spindles, axes, auxiliary devices etc. and selected other components to design the machine in a modular fashion and fulfil the customers' requirements. Each individual component class contains information related to the component itself and also business information such as cost, delivery time etc. In addition, the data model provides associativity and attributes between different components. The creation of these interdependent knowledge structures requires an OO approach in order to appropriately classify information. For example, `SkeletalElements` and `Spindle` can be defined as `MechanicalMachineComponents` and can inherit attributes of the `MechanicalMachineComponents` knowledge superclass. This can be applied to all technology elements of the DEMAT machine tool.

4.3 DEMAT data model

The requirements of a DEMAT machine tool have been classified based on the information identified in table 2. The DEMAT data model describes information related to the machine tool and also illustrates different levels of connectivity. In addition, the data model describes how each machine tool element is placed and located to other linked or neighbouring components. Figure 5 provides a partial UML representation of the data model. The three major classes are the `MachineTool` class the `MechanicalMachineComponent` class and the `Placement` class. The `MachineTool` class has component associations, including physical component information. The `MechanicalMachineComponent` class provides components with X, Y, Z dimensions and mass attributes. The `Placement` class enables different components to be positioned according to a location, X vector and Y vector.

Figure 5. A UML representation of the DEMAT data model

The partial representation of the DEMAT data model illustrated in figure 5 also incorporates the machines coordinate systems. Each component requires a reference coordinate system that can be referenced directly to the machine tools global coordinate system. Without this capability the different components have no direct relationship to each other. This has the potential to cause design problems when generating CAD models of the machine tool or if it used as part of a simulation. The global coordinate system of the machine tool is located on the external machine frame and each subsequent component coordinate is referenced to the global coordinate system. In this scenario it becomes easier to build a machine tool, without the need to re-edit and redefine locations and placements. This also provides traceability of the different components and can be used to develop working models, which can be used when process planning and simulating tool trajectories. Figure 6 provides an example of the coordinate systems.

Figure 6. Machine tool coordinate systems

The following, figure 7 provides an example of the different machine tool components and their attributes related to an example machine tool. In addition, an example visual representation of the different coordinate system is also provided for example components. This pictorially demonstrates machine tool component interconnectivity based on a global location perspective. This not only provides the attributes of the components, but also describes locations of each physical component in relation to other components. This is useful if the data model is to be used as part of a machine tool builder design environment.

Figure 7. Machine tool elements

Using this approach it becomes more efficient to design a DEMAT machine tool based on a customers requirements and on information stored within the database with regards to different possible components. In particular this approach also provides the capability to describe skeletal building blocks, which make up the vast majority of a DEMAT machine tools structure. The data model provides a method with which to generate the requirements of an individual machine tool, associated attributes and connections. This is particularly important for placement of the components in accordance with other components. For example; `MachineFrame` with `PhysicalMachineComponent.`

5 The DEMAT information sharing platform

5.1 The design of the information sharing platform database

The design of the database for capturing the relevant machine tool information is based on the data model as discussed in section 4. Based on this a relational database has been designed and implemented using PostgreSQL (www.postgresql.org 2013) as this provides commercial database functionality with the appropriate levels of security. In addition this is a platform independent database, providing functionality across different computing platforms. The database schema is illustrated in Figure 8, and represents lifecycle data related to each machine tool and component from negotiation and design through to monitoring and maintenance. From the machine tool point of view, the database contains detailed records on a single product including contract, design, cost and power consumption etc., and as a group of modular components. For each component, specific attributes are documented. The user can use the database to record each change made to the machine throughout its design and operational lifecycle. The machine tool vendor has the capability to take advantage of the database to collect data from the shop floor and monitor machine tool usage. Based on data collected from different machine tools, the vendor can predict machine failures, advise maintenance schedules and prevent possible interruption to production due to breakdowns. Using a database server all tasks can be performed remotely through wireless communication protocols minimising machine down time.

The database is not only used from a machine tool perspective, but also from a component level perspective. The database describes different types of spindles, axis drives etc., which can be used in a machine tool design. Each components consists of different information records, such as size, cost, energy behaviour etc. In addition these attributes can be updated (e.g. energy consumption) based on the use of the specific component. In this context and as an example within this research, energy behaviour of different components (spindles, drives etc) of a machine tool (Mori Seiki NL2000Y500, provided to KU Leuven by Machine Tool Technologies Research Foundation) has been characterised. This energy data can then be input in to the DEMAT data model.

Figure 8. Database schema for information sharing platform

For each individual type of component, a data table has been created with specific attribute fields. As shown in Figure 8, in the design phase, different tables are used to document different components. In each table, all available components are listed. Users are able to select appropriate components from the different tables to generate their machine tool. Since the same components can be used in different designs, each component is counted as an instance with a unique reference ID stored in a separate table. The corresponding data of every instance in terms of lifecycle records can then be stored in various data tables, which are linked by foreign keys to component tables and component instance table.

5.2 The DEMAT information sharing platform prototype

The ISP provides necessary user interfaces to communicate with the database including enquiring and writing data records. The functionality of the ISP and the relationship between the ISP and database are illustrated in Figure 9.

Figure 9. Information sharing platform (ISP) functionality

The ISP interface operates as an intermediate layer between the database and the engineering activities. At the initial stage, the user who is purchasing the machine tool can specify their needs, such as total cost, energy consumption anticipation etc. This contract information, through the ISP, is stored in the negotiation phase of the database. In the design stage, the user can build their machine tool using the available components listed in the database. The new machine design will be recorded in the database though the ISP. After the machine tool has been manufactured and delivered, monitoring data can also be captured directly into individual component sections of the database through the ISP. The data collection can be performed by direct input using the ISP interface or through various sensors installed on the machine tool to feedback remotely to the ISP. The monitoring parameters are defined as variables to monitor, frequency of acquisition, threshold values to trigger an alarm, and alarm types (message on machine HMI, sound, failure logs, trigger signals, etc.).

During the lifecycle of the machine tool, changes or scheduled maintenance can be captured by staff through the ISP. The ISP can handle various enquiries pertaining to the machine tool and components: failure rate of components, component age, component working hours left before next maintenance, machine availability computations: MTBF (Mean time between failures), MUT/MDT(), maintenance logs: duration, date, resources used, pertinence. Maintenance logs are also input into the ISP in this phase. A list of used parts is managed in this phase and can also be selected by customers. In addition, monitoring of machine component information provides lifecycle analysis, which can be used to predict future behaviour of the machine tool and also enable machine tool builders to develop more responsive and relevant machine tools. Consequently, the whole lifecycle of the machine tool can be captured and recorded. By providing necessary access to the database, different stakeholders related to the machine tool can share and use appropriate information. The machine tool vendor has the potential to store lifecycle records of each machine sold. Based on this, they can conveniently calculate the advantage and disadvantage of their products, make necessary improvements, provide further innovation to future machine tools and provide an enhanced aftercare service.

As shown in Figure 10, the user can create a new machine tool negotiation phase with their desired requirements and expectations, or bring up an existing one from the database. After the creation or modification of the machine tool specification, the database records can be updated. The following tabs in the interface are all based on this negotiation phase. For example; the current negotiation identification is 'M001D' in the design tab and is related to the design under this particular negotiation. If it is a newly proposed negotiation, the design, monitoring and lifecycle tabs will be empty.

Figure 10. Information sharing platform

Figure 11 shows the interface for designing a machine tool by enabling the user to pick required machine tool components. By selecting the appropriate component type (such as ‘controller’), the ISP will list all the component (controller) options from the database. This can be populated with a wide variety of different components that the machine tool builder can use and interface with. As shown in figure 11, three different example controllers are listed on the right. By selecting components and adding to the live design on the left, a tree structure of the machine tool can be created and updated accordingly. The total cost of the machine tool can be calculated based on the various different component selections throughout the build phase.

Figure 11. Information sharing platform view 2

Upon delivery of the machine tool the ISP can be configured to remotely capture and log machine tool status information to note alarms or variables. The level of machine tool information capture is dependent on the types and range of sensors that are incorporated into the machine tool in the design phase. The ISP provides an interface to capture information by shop floor engineers. For repairs or maintenance the required workload, breakdown duration, repair procedure will be documented to provide a reliable means with which to monitor the machine tool throughout its lifecycle. This can be thought of as being a digital logbook that is continuously updated. This information is critical as it provides the machine tool builders and various component builders real time data, enabling them to produce improved machine tools and components. In addition, the digital logbook can be used when selling the machine tool, providing a more enhanced view of the machine life to date.

The developed ISP is a prototype of the architecture described in this paper. Some functionality is still to be developed such as the interaction with a CAD system for a complete machine design builder environment, and the sensor feedback from the shop floor to the database. The ISP prototype provides a vision of the advantage for the machine tool end user and vendor of using a system that logically categorises all machine tool information. Figure 12 illustrates the view of the ISP, the 4 different phases and its integration with the DEMAT data model as discussed in section 4.3.

Figure 12. The complete ISP architecture

6 Case study and example for the ISP

In order to demonstrate the functionality of the ISP a simple case study was generated based on an existing 3-axis vertical machining centre example. The database was populated with components taken from a CAD model. Example total design costs and maintenance costs were also used to demonstrate cost functionality of the platform. Figure 13 illustrates the negotiation phase of the ISP with a full machine tool specification. Figure 14 shows the design phase, where all specific components of the machine tool are listed. The designer can select individual components. The total cost is also monitored throughout the design phase and should not exceed the negotiation cost.

Figure 14 depicts the monitoring phase of the ISP. Each separate component of the machine tool, which can be sensor monitored will log information directly to the database. This will include alarms, energy consumed and maintenance protocols. The purpose of this is to move away from the traditional view of buying a machine tool. Instead, with this approach customers are in effect buying a machine tool service contract, which continuously monitors the health of their specific machine tool. This has the potential to lead towards a more robust and responsive machine tool and provide new business models. At present, state of the art machine tool maintenance systems have been developed by DMG Mori Seiki (www.moriseiki.co.uk 2013). Whilst these proposed systems provide required machine maintenance information, the information is logged and not sent to the manufacturer. The final phase in the ISP is the lifecycle management of the machine tool as depicted in Figure 15. This will log lifecycle information pertaining to the individual components, such as component age, failure rate, and maintenance servicing.

Figure 13. ISP negotiation phase

Figure 14. ISP Design phase

Figure 15. ISP monitoring phase

Figure 16. ISP lifecycle phase

7 The future vision of machine tool design

Dematerialisation of machine tools is an emerging concept that has the potential to change the landscape of global manufacturing and provide a more reactive and adaptive machine tool sector. The different machine tool elements each have specific information requirements. This information is used to build a customer specific DEMAT machine tool. This information is stored and linked together into a relational database providing complete data integrity and data transparency. The vision of a DEMAT machine tool also extends towards capturing sensor information from the various components which enables real time monitoring of the machine tool throughout its life cycle. This in turn will enable machine tool manufactures to better understand their product lifecycles and in turn address key issues and fundamentally design better machine tools. Figure 17 depicts a conceptual view of the complete ISP from negotiation through to lifecycle management of the machine tool. In addition, a graphical user interface is demonstrated as an imbedded design environment. This allows the user and the customer to directly view the design and complete costing of their machine tool.

Figure 17: A conceptual view of the ISP

8 Conclusions

This paper has demonstrated the vision of the DEMAT machine tool consisting of different components. A machine tool data model is presented describing information and interactions between different components of the machine tool. For example `Axis`, `Sensors`, `Auxiliary` devices etc. The presented UML approach describes a view of the different component interactions, which are linked directly to a relational database. Finally an ISP prototype is developed allowing the user to design DEMAT machine tools. The ISP illustrates a view of the finished system providing a novel information rich method to develop customer specific DEMAT machine tools. The unique contributions of this research are the categorising of machine tool components, the development of a data rich model and the generation of a prototype ISP to realise the wider vision of next generation machine tools.

Future work will consist of developing a digitally informed machine tool builder design environment to provide further real time design functionality. This information rich design environment will also be linked directly to different machine tool suppliers, thus providing enhanced machine component information and enable the vision of the DEMAT machine tool to be further extended.

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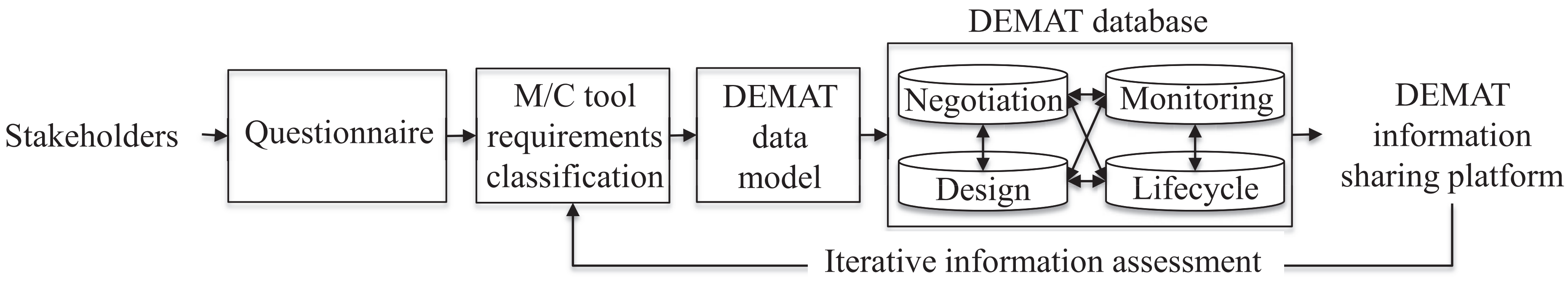
	NAME	PROFILE	CATEGORAY
1	TECNALIA	Technology centre	Research centre
2	CECIMO	European Association of Machine Tool Industries	Technical institute
3	Ibarmia	Machine tools design and manufacture	SME – Machine builder
3	Ibarmia	Machine tools design and manufacture	SME – Machine builder
4	Micromega	Service and support related to vibration and high accuracy positioning	SME – Machine component supplier
5	CESI	Precision machine tools	SME – Machine builder
6	D.Electron SRL	Control development and advanced sensor technology	SME – Control builder
7	NC-SERVICE	Life-cycle analysis– Reuse of machine tools	SME
8	Intelliact	Software development – Requirements for machine structure	SME
8	Intelliact	Software development	SME
9	Missler	Software development – Information models / DEMAT smart design environment	SME
10	CNR-ITIA	Research – Holistic optimization	Research Institute
11	KULeuven	Research – Information requirements / data modelling	University
11	KULeuven	Research – Information requirements / data modelling	University
12	EPFL	Research – Holistic process planner / green monitoring / factory simulation environment	University
13	Fraunhofer -ISI	Research – Use case studies / business processes and models	Research Institute
14	Bath	Research – Information requirements / data modelling	University
15	UStutt	Research – Holistic control and controlled behaviour	University
16	MCM	Machine tool design and manufacture	MME – Machine tool builder

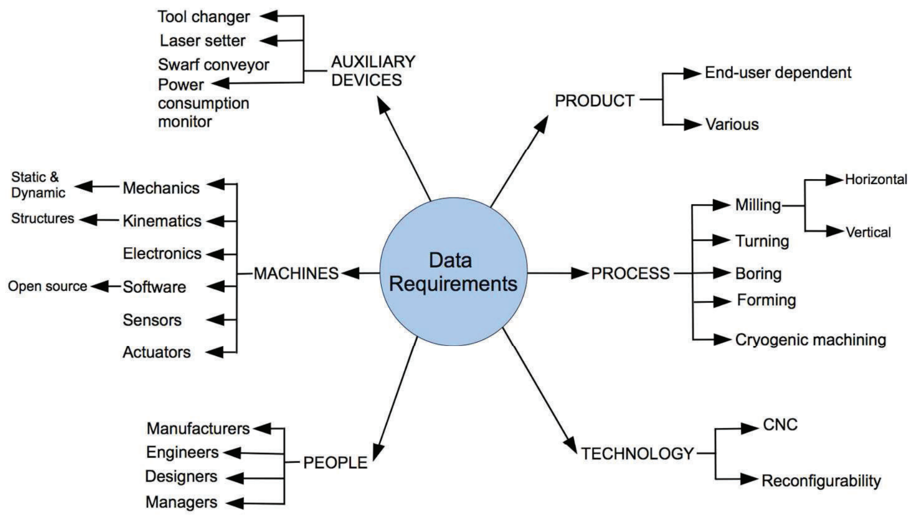
Table 1. DEMAT stakeholders

STAKEHOLDERS	*End-user*		*Machine builder*		*Component suppliers*		*Auxiliary device suppliers*	
	define	use	define	use	define	use	define	use
Machine specification								
Machine market position	x			x		x		x
Machine cost	x		x			x		x
Machine power		x	x			x		x
-Energy saving recommendations		x	x		x			x
Machine type, processes: Milling	x	x	x			x		x
Machine physical size (dimensions)	x		x	x		x		x
- Work envelope size	x		x			x		x
- Machine carcass / guarding		x	x			x		x
- Machine weight		x	x			x		x
- Accuracy, repeatability and tolerance capability		x	x			x		x
- Machine kinematics - X, Y, Z		x	x			x		x
- Number of axis and axis management	x		x			x		x
- High speed machining capability		x	x			x		x
Cooling / lubrication (Low / high pressure)		x	x			x		x
- Coolant tanks		x	x			x		x
Air requirements		x	x			x		x
Tool turret / housing		x	x			x		x
- Number of tools		x	x			x		x
Hydraulic and pneumatic systems		x	x	x		x		x
Feedrate profile		x	x	x		x		x
- Axial force feedback		x	x			x		x
- Axial feed drives		x	x			x		x
Spindle type	x	x	x	x		x		x
- Spindle torque profile		x	x			x		x
- Spindle force feedback		x	x			x		x
- Machine bearings		x	x			x		x
Positioning systems of the machine		x	x	x		x		x
- Linear guide ways		x	x		x			x
- Ball screws		x	x		x			x
- Encoders		x	x		x			x
- Servo drives		x	x		x			x
Material compatibility		x	x	x		x		x
Temperature compatibility		x	x			x		x
Flexibility	x			x		x		x
Maintenance		x	x			x		x
- Servicing intervals		x	x			x		
Controller		x	x			x		x
Controller type and capability		x	x			x		x
- Motion controller		x	x	x	x			x
- Custom controller interface	x		x	x	x	x		x
- CNC hardware requirements		x	x	x		x		x
- Black box functionality		x	x			x		x
- PLC requirements		x	X			x		x
- Connectivity		x	x			x		x
- Operating system		x	x			x		x
- Language required		x	x			x		x
- Part simulation capability		x	x			x		x
- Virtual machining capability		x	x			x		x
Sensors		x	x		x			x
- Air pressure monitoring		x	x	x	x			x
- Energy consumption monitoring		x	x	x	x			x
- Force and load feedback		x	x	x	x			x
- Decibel monitoring		x	x	x	x			x
- Ultrasonic actuators		x	x	x	x			x
- Monitoring and minimisation of vibrations		x	x	x	x			x
Commands		x		x		x		x

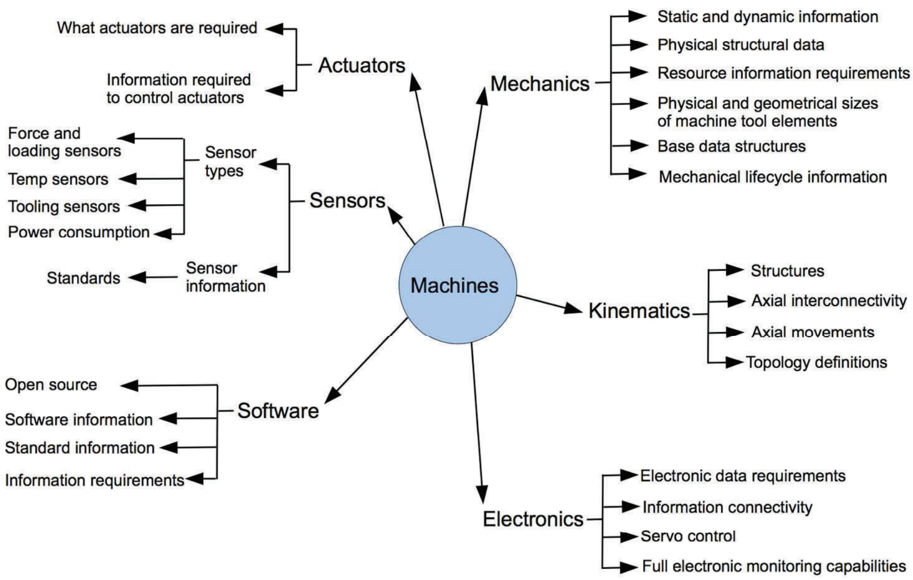
- Syntax		x	x			x		x
- Specific programming macros		x	x			x		x
- Controller cycles / Canned cycles		x	x			x		x
Physical transfer interface	x		x			x		x
- Memory		x		x		x		x
- Look-ahead		x		x		x		x
- Digital I/O number		x		x		x		x
- Analogue I/O number		x		x		x		x
- Number of interpolation channels		x		x		x		x
Auxiliary devices		x		x		x	x	
- Cost of auxiliary devices		x		x		x	x	
- Additional rotary axes		x		x		x	x	
- Speed increaser		x		x		x	x	
- Swarf / chip conveyor		x		x		x	x	
- Material handling system		x		x		x	x	
- Robotic loading / unloading		x		x		x	x	
- Pallet changer		x		x		x	x	
Interface		x	x		x	x		x
- Alphanumeric Keyboard		x		x	x			x
- Portable terminal		x		x	x			x
- touch screen interface		x		x	x			x
- Machine keyboard		x		x	x			x
- Hand wheel control		x		x	x			x
Fixtures	x			x		x		x
Tool setter / checker		x		x			x	
Probing and online inspection		x		x			x	
Automatic tool changer		x	x			x		x
Consumables		x		x		x		x
- Cutting tools / back-end holders		x		x	x			x
- Number of tools in the machine	x			x	x			x
- Maximum tool size	x			x	x			x
- Oil / lubrication		x		x	x			x
- Types of coolants		x		x	x			x
- Types of filters		x		x	x			x
Standards		x		x		x		x
Part replacements		x	x	x		x		x
Labour / production / enterprise		x	x			x		x
- Personnel skills / qualification requirements		x		x				
- Personnel costs	x							
- Shift and opening hours	x							
Batch size	x			x		x		x
- Organisation of demand	x			x				
- Produce for assembly / stock	x			x				
Overload management	x			x		x		x
- ERP	x			x				
CAD/CAM	x	x	x	x		x		x
Tool Data Management		x		x		x		x
Size of the order of the machine	x			x		x		x
Health and safety implications		x	x			x		x

Table 2: The different stakeholder information requirements

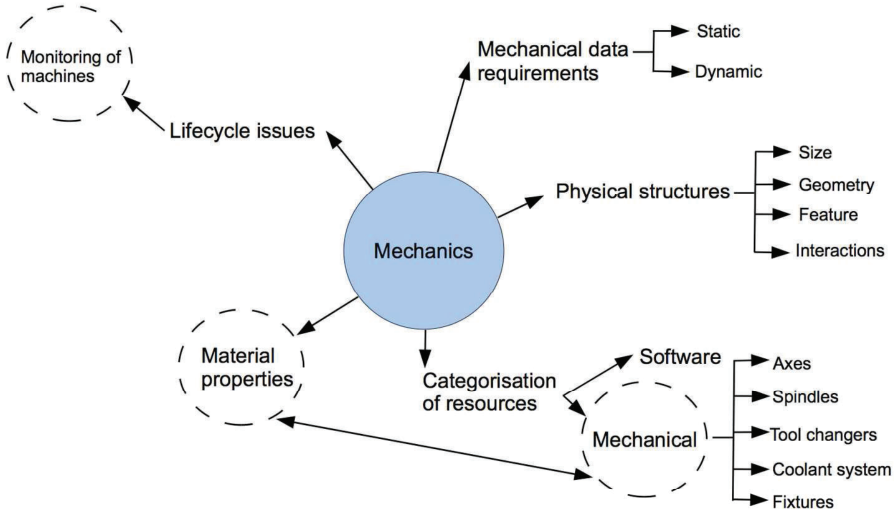

Stakeholders
Questionnaire
M/C tool requirements classification
DEMAT data model
DEMAT database
Negotiation
Monitoring
Design
Lifecycle
DEMAT information sharing platform
Iterative information assessment



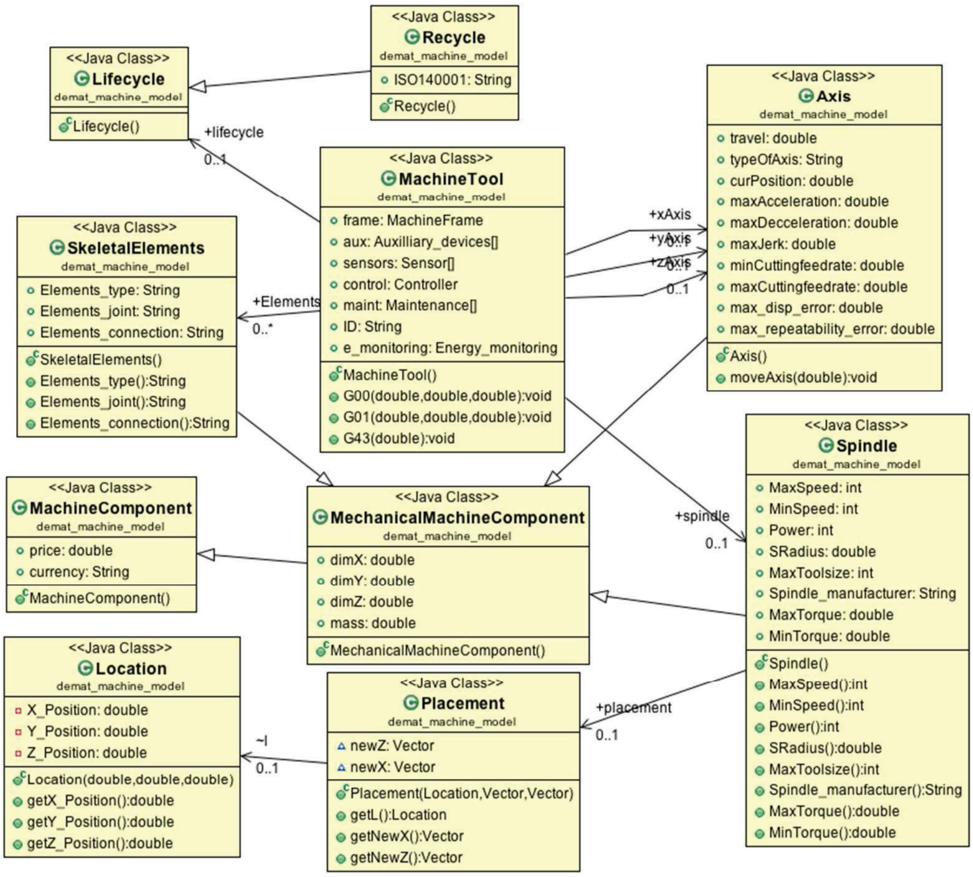
297x209mm (150 x 150 DPI)



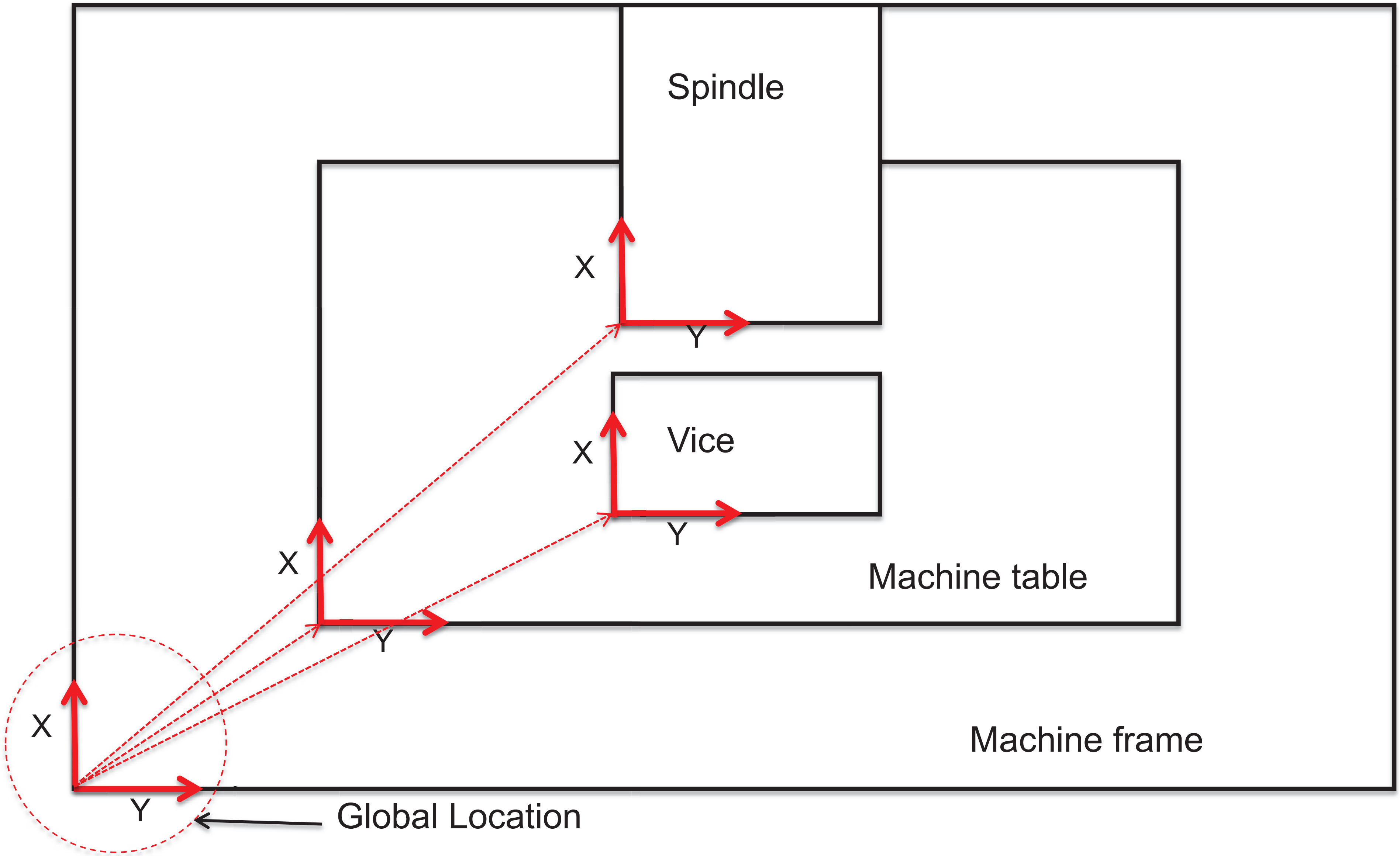
297x209mm (150 x 150 DPI)

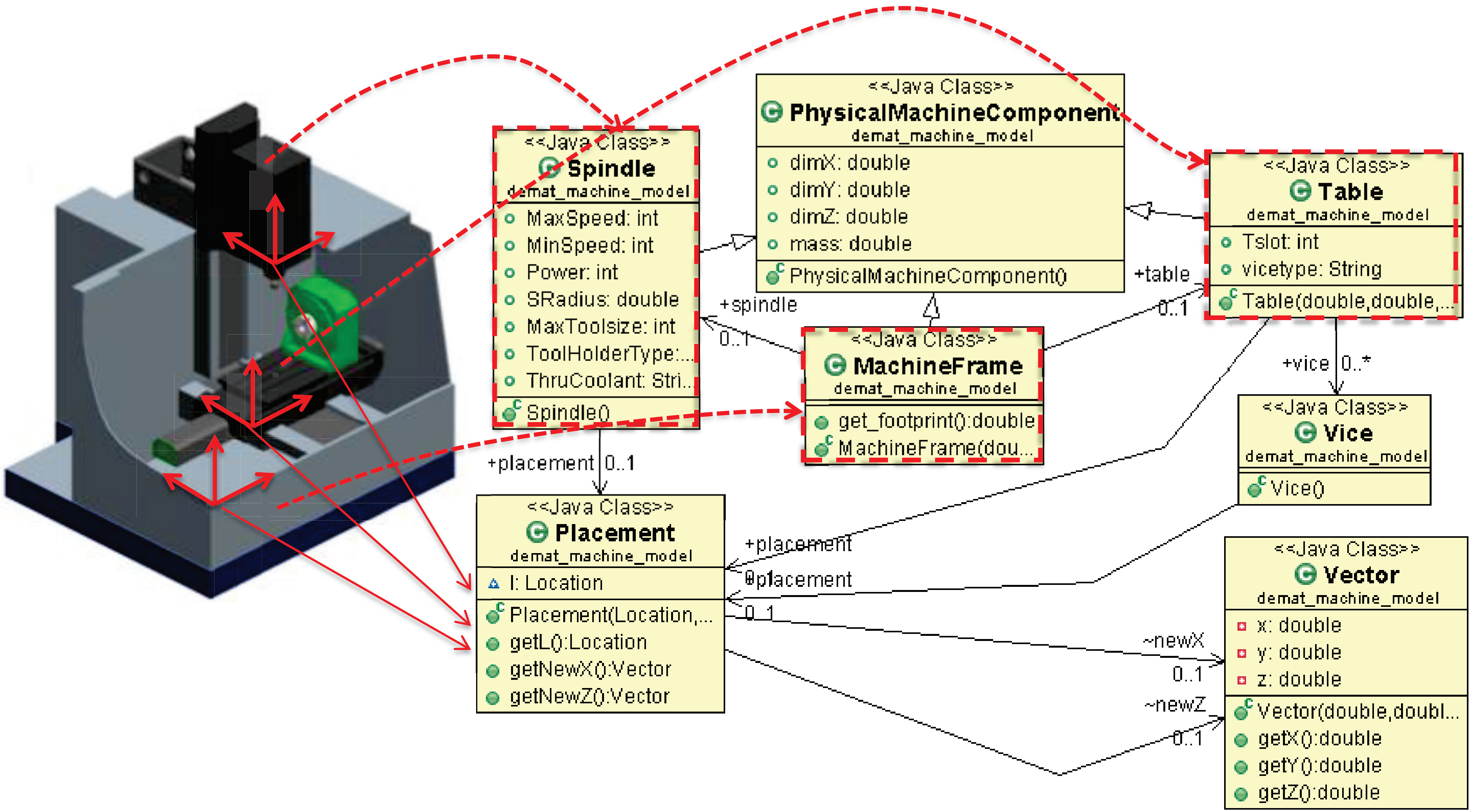


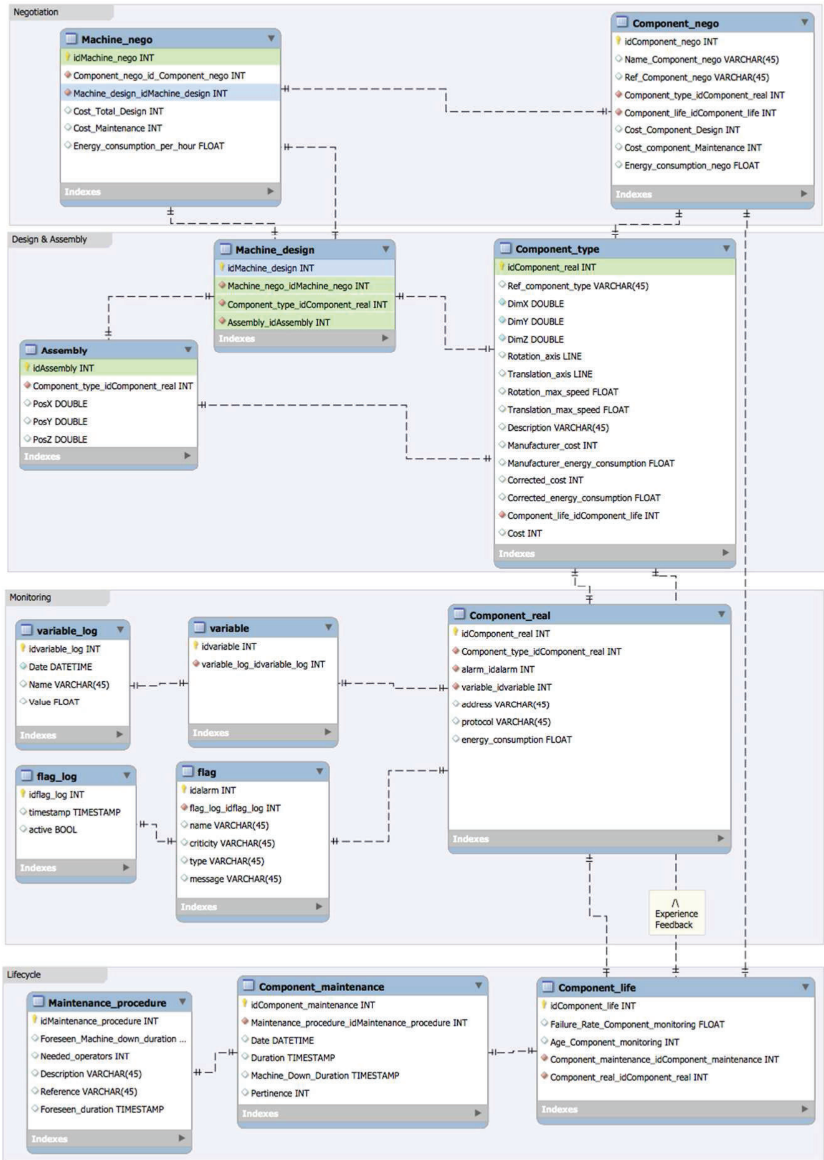
297x209mm (150 x 150 DPI)



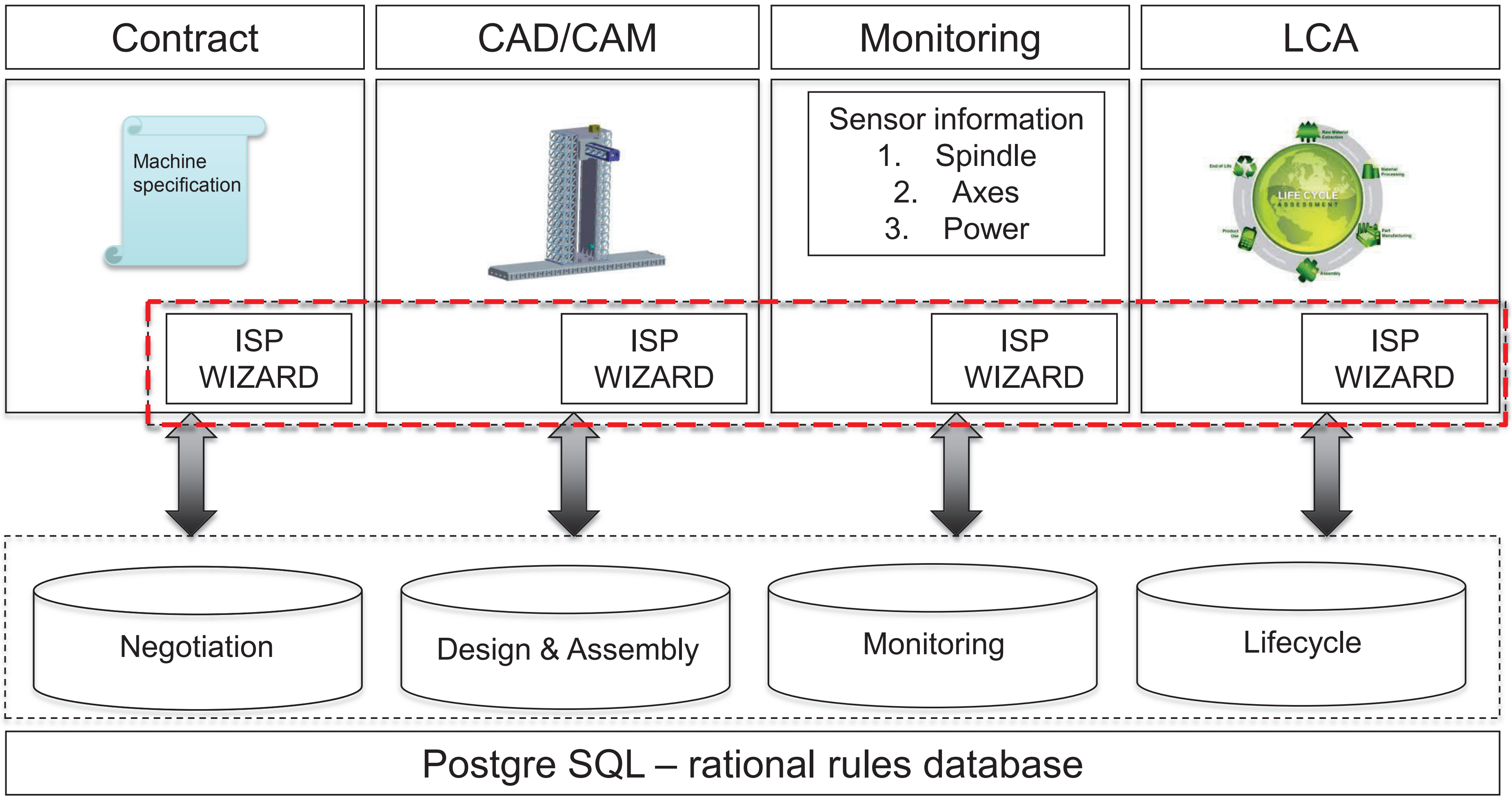
291x261mm (72 x 72 DPI)

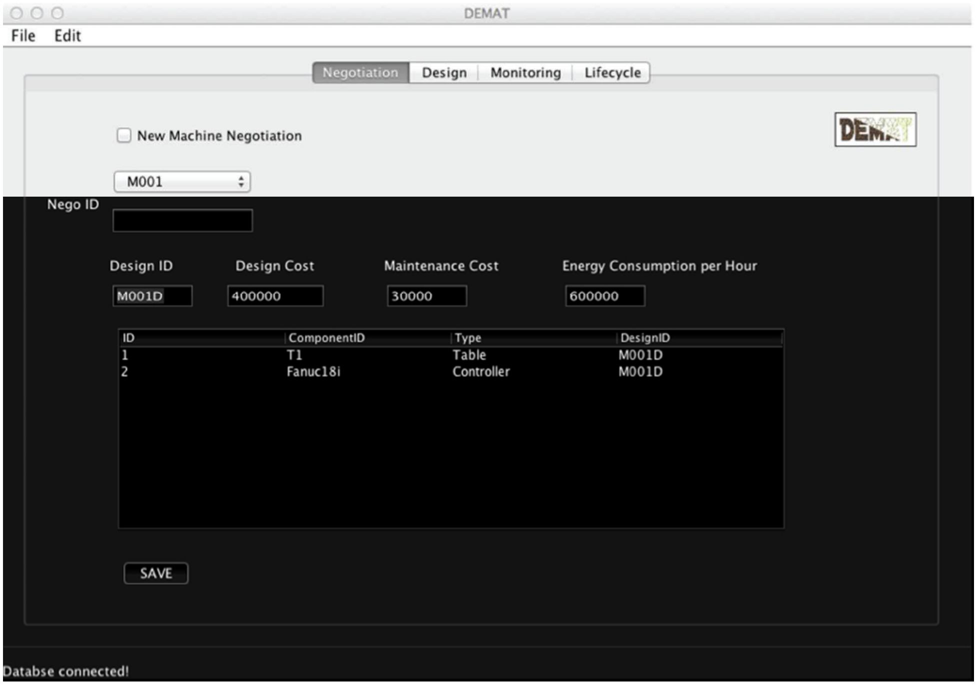

Spindle
X
Y
Vice
X
Y
X
Y
Machine table
X
Y
Machine frame
Global Location


<<Java Class>>
Spindle
demat_machine_model
MaxSpeed: int
MinSpeed: int
Power: int
SRadius: double
MaxToolsize: int
ToolHolderType:...
ThruCoolant: Stri...
Spindle()
<<Java Class>>
PhysicalMachineComponent
demat_machine_model
dimX: double
dimY: double
dimZ: double
mass: double
PhysicalMachineComponent()
<<Java Class>>
Table
demat_machine_model
Tslot: int
vicetype: String
Table(double,double,...
+table
0..1
+spindle
0..1
<<Java Class>>
MachineFrame
demat_machine_model
get_footprint():double
MachineFrame(dou...
+vice
0..*
<<Java Class>>
Vice
demat_machine_model
Vice()
+placement
0..1
<<Java Class>>
Placement
demat_machine_model
l: Location
Placement(Location,...
getL():Location
getNewX():Vector
getNewZ():Vector
+placement
0..1
~newX
0..1
~newZ
0..1
<<Java Class>>
Vector
demat_machine_model
x: double
y: double
z: double
Vector(double,doubl...
getX():double
getY():double
getZ():double

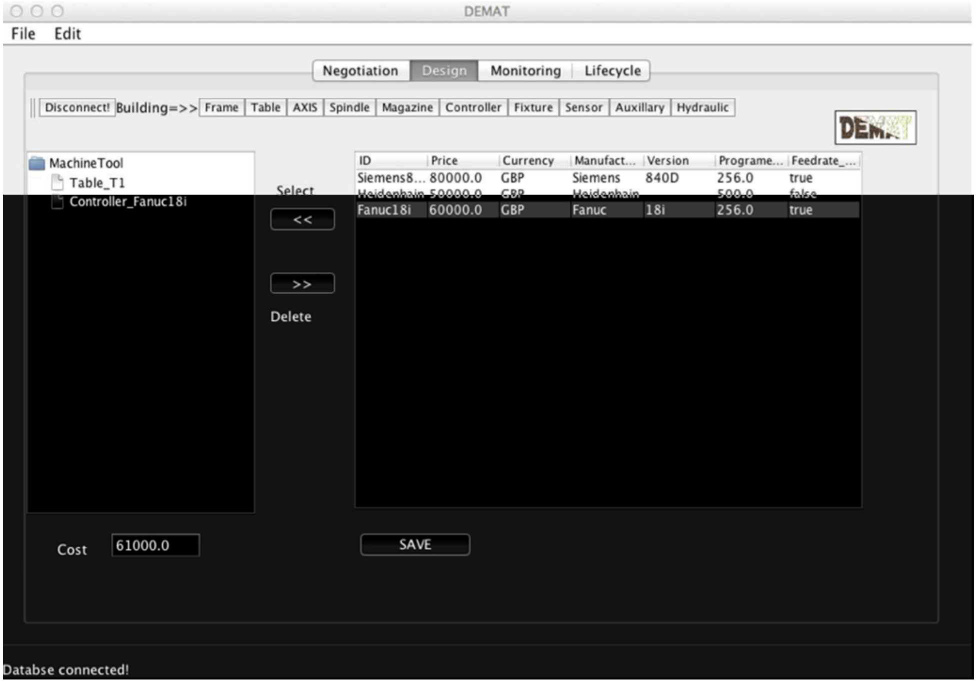


167x234mm (150 x 150 DPI)

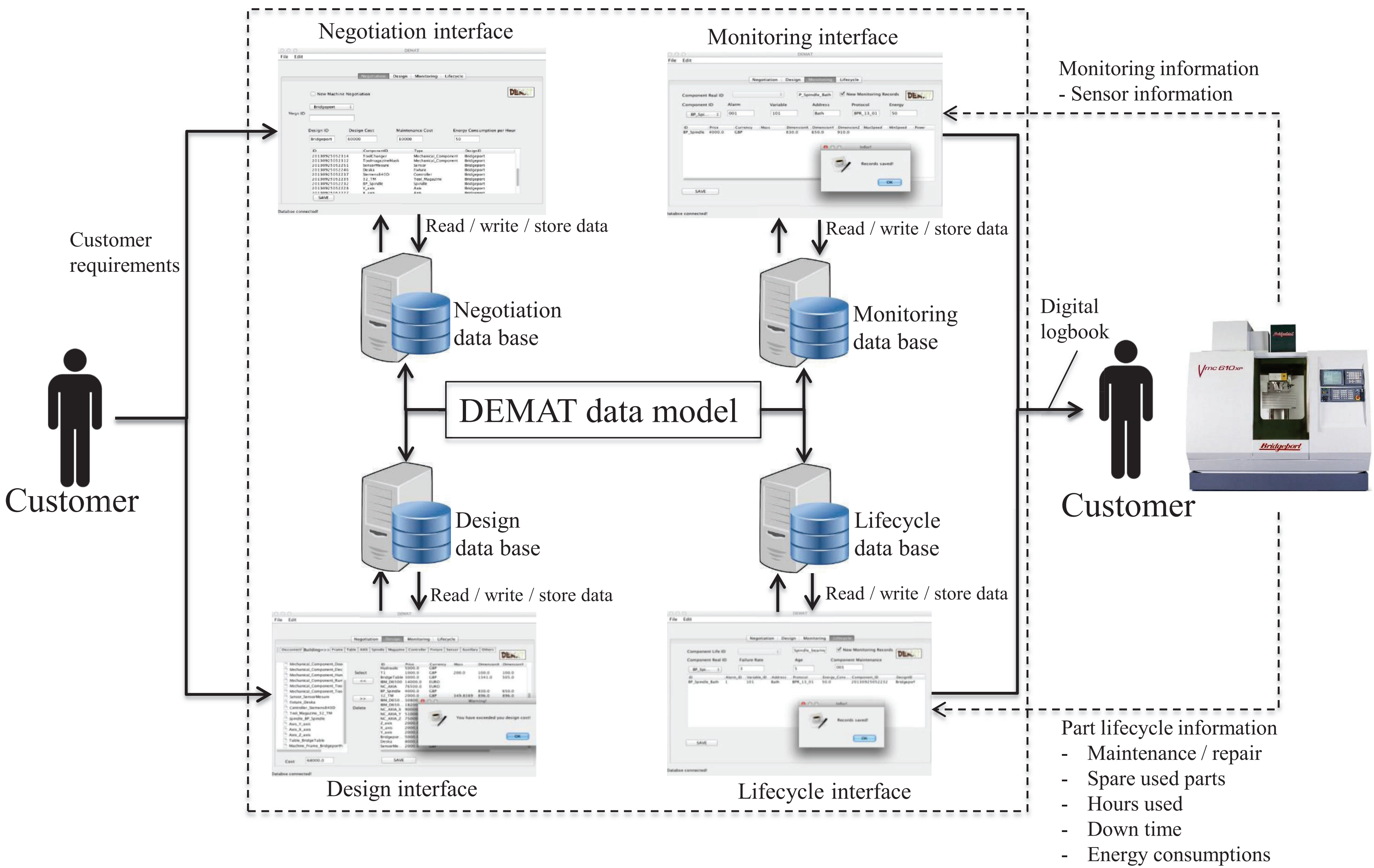

Contract
CAD/CAM
Monitoring
LCA
Machine specification
Sensor information
1. Spindle
2. Axes
3. Power
LIFE CYCLE ASSESSMENT
ISP WIZARD
ISP WIZARD
ISP WIZARD
ISP WIZARD
Negotiation
Design & Assembly
Monitoring
Lifecycle
Postgre SQL – rational rules database



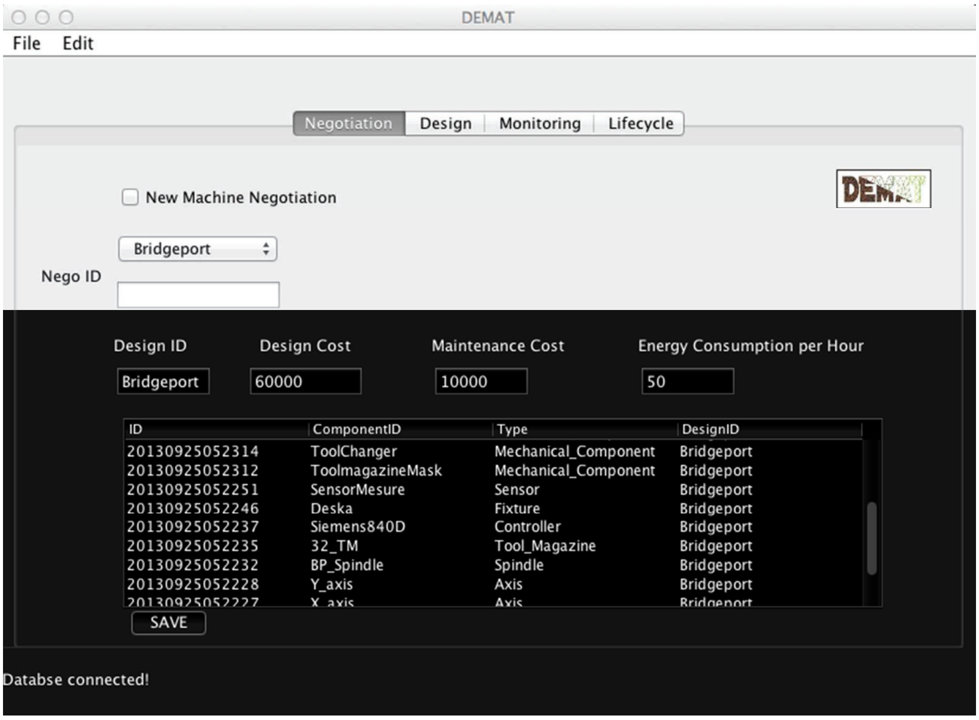
150x104mm (150 x 150 DPI)



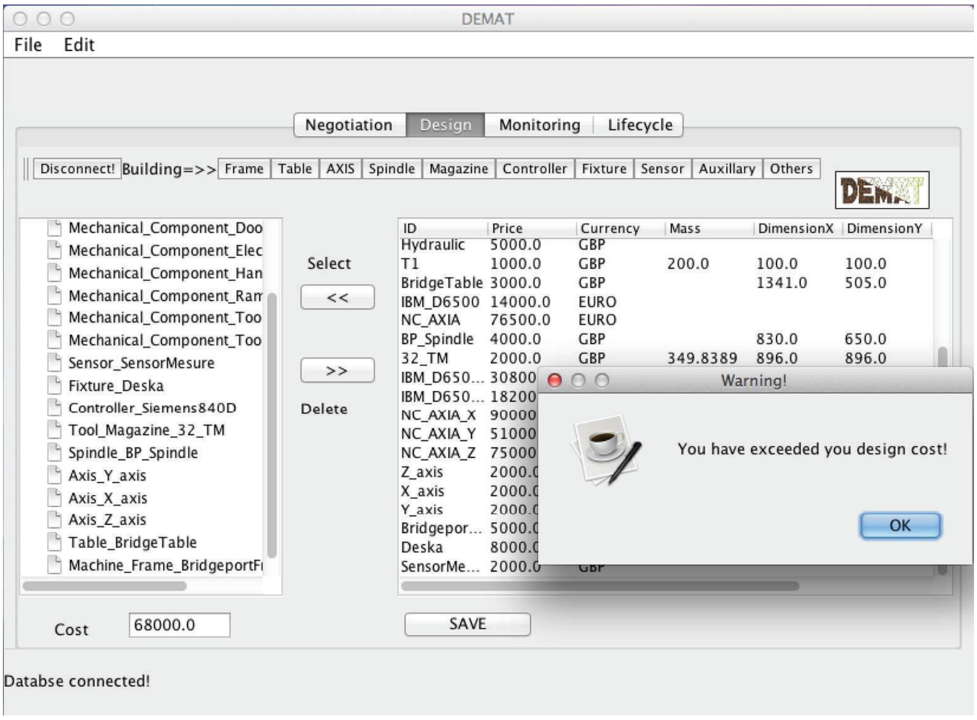
150x104mm (150 x 150 DPI)



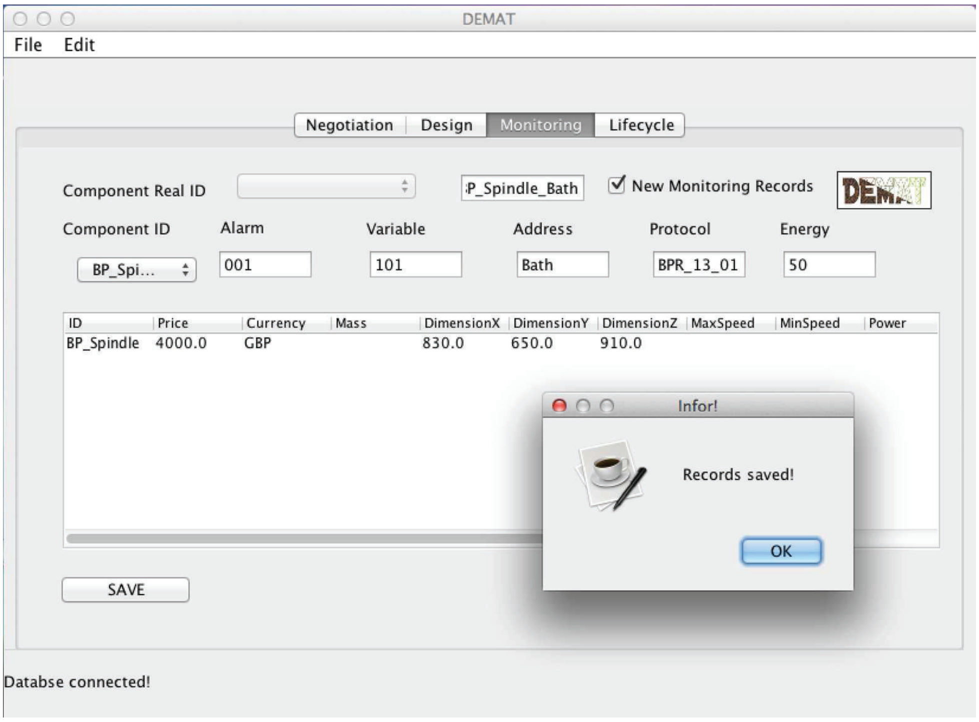
Negotiation interface
Monitoring interface
Monitoring information
- Sensor information
Customer requirements
Read / write / store data
Read / write / store data
Negotiation data base
Monitoring data base
Digital logbook
DEMAT data model
Customer
Customer
Design data base
Lifecycle data base
Read / write / store data
Read / write / store data
Design interface
Lifecycle interface
Part lifecycle information
- Maintenance / repair
- Spare used parts
- Hours used
- Down time
- Energy consumptions



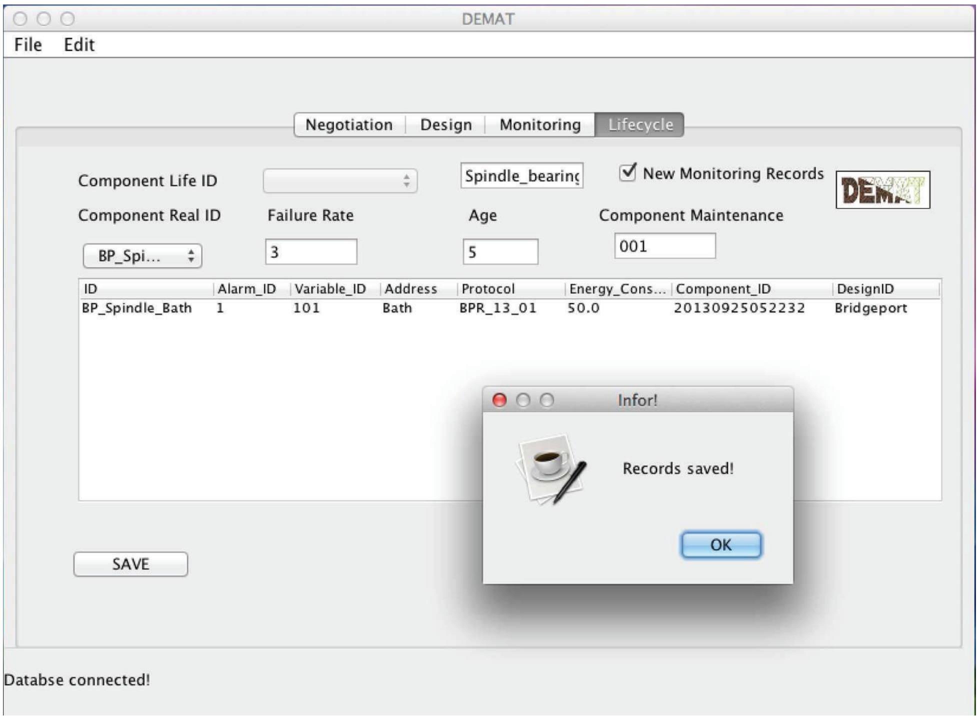
289x211mm (72 x 72 DPI)



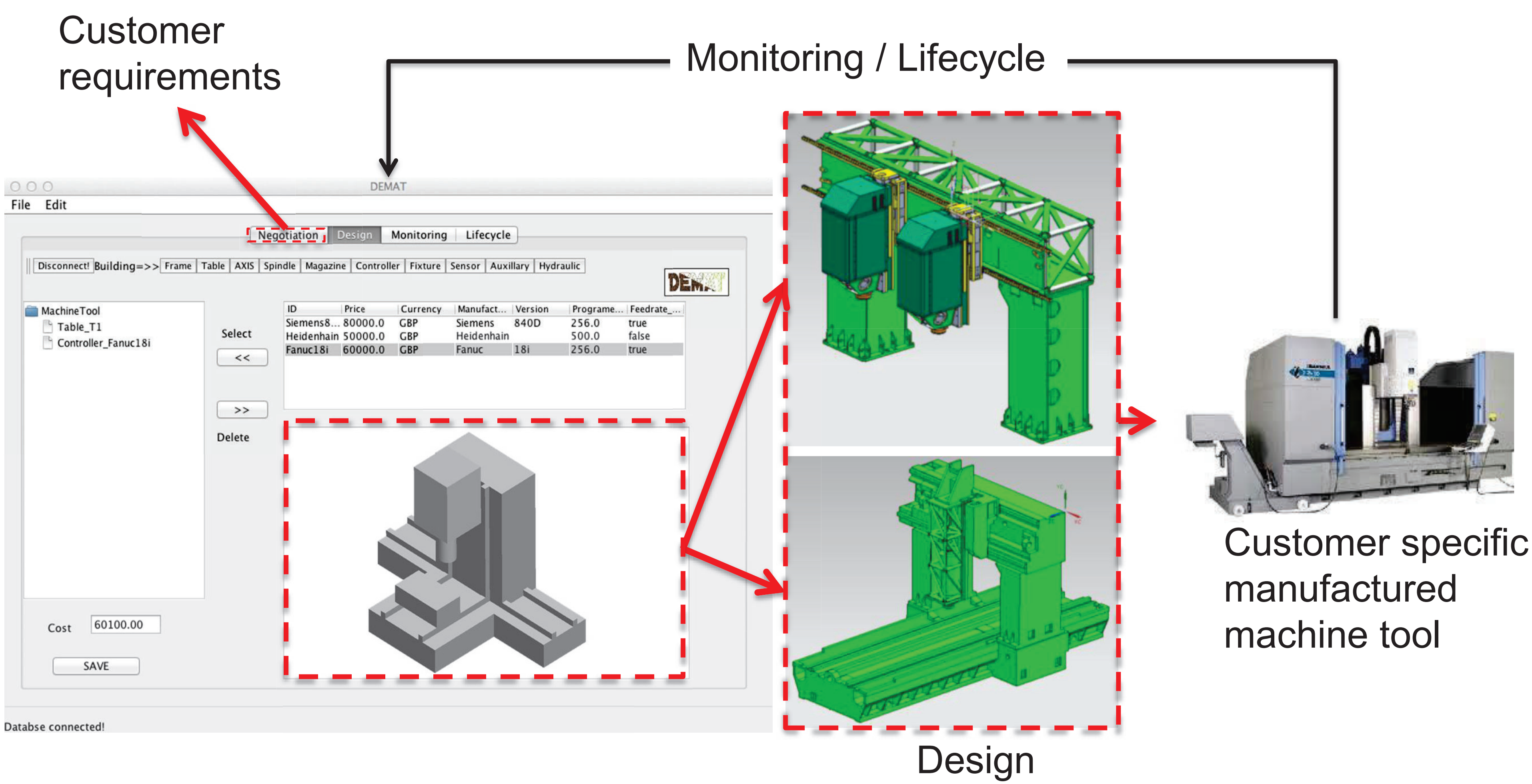
289x211mm (144 x 144 DPI)



289x212mm (144 x 144 DPI)



289x212mm (144 x 144 DPI)


Customer requirements
Monitoring / Lifecycle
DEMAT
File Edit
Negotiation
Design
Monitoring
Lifecycle
Disconnect! Building=>> Frame Table AXIS Spindle Magazine Controller Fixture Sensor Auxillary Hydraulic
MachineTool
Table_T1
Controller_Fanuc18i
Select
<<
>>
Delete
ID Price Currency Manufact... Version Programe... Feedrate_...
Siemens8... 80000.0 GBP Siemens 840D 256.0 true
Heidenhain 50000.0 GBP Heidenhain 500.0 false
Fanuc18i 60000.0 GBP Fanuc 18i 256.0 true
Cost 60100.00
SAVE
Databse connected!
Design
Customer specific manufactured machine tool